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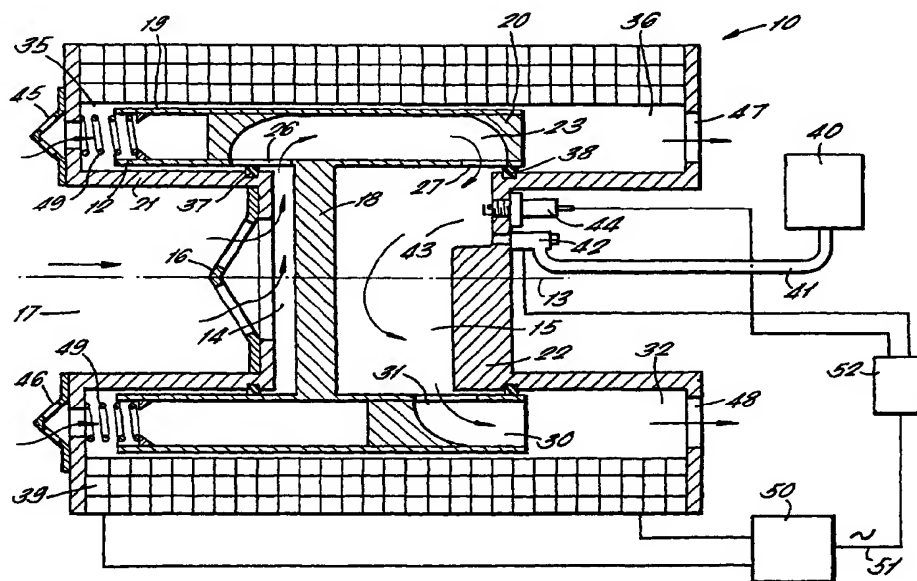
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(54) Title: CYCLICALLY OPERATED FLUID DISPLACEMENT MACHINE



(57) Abstract: A displacement machine (10) comprises a housing (11), a reciprocating member (12) reciprocable linearly along an axis of reciprocation (13) in the housing (11) and defining with the housing (11) first (14) and second (15) variable volume chambers. A fluid inlet (17) is connected to the first variable volume chamber (14). A fluid outlet (18) is connected to the second variable volume chamber (15). An inlet valve (16) allows flow of fluid through the fluid inlet (17) into the first variable volume chamber (14) and prevents flow of fluid from the first variable volume chamber (14) out of the fluid inlet (17).

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## CYCLICALLY OPERATED FLUID DISPLACEMENT MACHINE

5 The present invention relates to a cyclically operated fluid displacement machine.

10 The present invention can provide a cyclically operated fluid displacement machine either in the form of an engine or a compressor.

15 The present invention aims to provide a machine which is very simple and in particular which does not require a valve train system, separate alternator and starter motor or cam shaft. The machine of the present invention could be used as an engine in a hybrid vehicle, the engine producing electrical power which would then be used by electrical motors to power the vehicle.

20 US Patent No.US-A-5172784 describes an arrangement for powering a hybrid vehicle which comprises external combustion Stirling engines coupled to linear generators and used in conjunction with a battery pack to power electric motors for a vehicle.

25 US Patent US-A-4924956 describes a tandem double-acting free piston engine comprising a housing including a cylinder having first and second combustion chambers at opposite ends thereof and a third combustion chamber between the ends. One double acting piston is displaceable between the first and third combustion chamber. A second double acting piston is displaceable between the second and third combustion chambers. The two double acting pistons are linked so that they move in timed relationship

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with each other. A linear alternator is combined in the engine by attaching one coil to each of the double acting pistons and by surrounding the cylinder with other electrical coils, the fields of which are  
5 intersected by the coils on the two pistons.

The present invention provides a cyclically operated fluid displacement machine which comprises:

- a housing;
  - 10 a reciprocating member reciprocal linearly along an axis of reciprocation in the housing and defining with the housing first and second variable volume chambers;
  - a fluid inlet connected to the first variable  
15 volume chamber;
  - a fluid outlet connected to the second variable volume chamber;
  - inlet valve means which allows flow of fluid through the fluid inlet into the first variable volume  
20 chamber and which prevents flow of fluid from the first variable volume chamber out of the fluid inlet;
  - transfer valve means which allows flow of fluid from the first variable volume chamber to the second variable volume chamber and which prevents flow of  
25 fluid from the second variable volume chamber to the first variable volume chamber;
  - outlet valve means which allows flow of fluid from the second variable volume chamber out of the fluid outlet and which prevents flow of fluid from the  
30 fluid outlet into the second variable volume chamber;
- wherein:
- during movement of the reciprocating member in the housing in a first direction fluid is drawn into the first variable volume chamber and the fluid in the  
35 second variable volume chamber expelled from the

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second variable volume chamber via the fluid outlet;  
and

5 during movement of the reciprocating member in  
the housing in a second direction, opposite to the  
first direction, fluid is compressed in the first  
variable volume chamber and fluid is transferred from  
the first variable volume chamber via the transfer  
valve means to the second variable volume chamber;

characterised in that:

10 the reciprocating member comprises a middle  
section which extends perpendicularly of the axis of  
reciprocation and two end sections on opposite sides  
of the middle section, each of the end sections  
comprising a wall extending generally parallel to the  
15 axis of reciprocation and each of the end sections  
defining with the middle section an open-ended  
cylinder open at one end;

the housing has a first piston portion which  
extends into a first of the open-ended cylinders of  
20 the reciprocating member and which acts as a piston in  
the first open-ended cylinder with the first piston  
portion and the first open-ended cylinder together  
defining the first variable volume chamber; and

the housing has a second piston portion which  
25 extends into a second of the open-ended cylinders of  
the reciprocating member which acts as a piston in the  
second open-ended cylinder with the second piston  
portion and the second open-ended cylinder together  
defining the second variable volume chamber.

30 The construction of the machine given above  
provides an engine or a compressor which has a reduced  
weight at reduced cost and is simple. In effect, the  
machine has a single moving member. The machine would  
35 be ideal, for instance, for use as an engine in a

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hybrid vehicle.

Preferably, the reciprocating member has a generally circular radial cross-section and the end sections each comprise an annular wall spaced from a central axis of the reciprocating member.

Making the reciprocating member circular in cross-section eases the manufacture of the machine as a whole.

Preferably, an electrical winding is provided in the housing surrounding the reciprocating member, the electrical winding extending parallel to and adjacent to the end-section walls of the reciprocating member.

The present invention can provide a very compact and simple combined machine and electrical power generator. By locating the winding next to the reciprocating member more power and/or greater electrical control is provided. The construction of the engine can allow the greater percentage of the work of the piston in an engine to be extracted and also the construction of machine allows electrical force to be used efficiently to compress gas in a compressor or to compress fuel/air mixture in an engine. Electrical control can also be used to control the position of the reciprocating member accurately.

Preferably, the electrical winding extends parallel to the axis of reciprocation on the reciprocating member and has a length equivalent to at least the sum of the axial length of the reciprocating member and the distance travelled by the reciprocating

- 5 -

member in each reciprocation. This ensures good efficiency.

5 Preferably the end section walls of the reciprocating member are slidable in slots defined in the housing and the electrical winding in the housing extends adjacent to, and parallel with, surfaces defining the slots. Preferably a seal is formed between the end sections of the reciprocating member and the slots in which the end section slides.

10 In some embodiments resilient means acts between the housing and the reciprocating member to bias the reciprocating member to move in one direction. Preferably the resilient means act to bias the reciprocating member to reduce the second variable volume chamber to a minimum volume.

20 The reciprocating member in the present machine is essentially a free motion member. In the prior art, free motion pistons have tended to be used in diesel engines or in Stirling engines. In diesel engines combustion could be ensured by the functioning of the diesel cycle. However, the engines tend to be fairly large and bulky. Stirling engines lack the benefit of internal combustion. The resilient means biasing the reciprocal member could comprise a standard coiled spring or a gas spring. The machine could be configured to work at a frequency equivalent to its resonant frequency, e.g. 3000 rpm. The machine could also be operated by pausing the reciprocating member at a convenient point, with the duration of the pause being variable to vary power output.

35 Preferably, each of the inlet valve means, the

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outlet valve means and the transfer valve means comprises either a one-way valve which opens and closes under the action of a pressure differential thereacross or a ported valve comprising a port  
5 opening onto one of the variable volume chambers which is cyclically opened and closed by the reciprocating member during reciprocation.

The present invention can remove the need for a  
10 complicated valve train system. The present invention when used as an engine can combine an alternator and a starter motor by using electrical winding.

The present invention does away with the need for  
15 a cam shaft to control movement of valves. The present invention works essentially on a two-stroke cycle when the invention is used as an engine.

Preferably the inlet valve means comprises a  
20 spring-biassed one-way valve.

In one embodiment the machine described before functions as an internal combustion engine, wherein:  
a charge of air is drawn into the first variable  
25 volume chamber via the fluid inlet;  
the charge of air drawn into the first variable volume chamber is compressed;  
the compressed charge of air is delivered via the transfer valve means to the second variable volume  
30 chamber;  
the machine comprises fuel delivery means which delivers fuel to a second variable volume chamber for mixing with the compressed charge of air;  
the compressed charge mixture of fuel and air is  
35 combusted and allowed to expand in the second variable

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volume chamber; and

the expanded combusted mixture is scavenged from the second variable volume chamber by a subsequent charge of air delivered to the second variable volume chamber via the transfer valve means.

The present invention provides a very simple construction of engine, with essentially only one moving part.

10

Preferably the fuel used in the engine is compressed natural gas and the machine comprises storage means for storing natural gas in a pressurised state and fuel delivery means controls the flow of the pressurised natural gas into the second variable volume chamber without use of pumping means. The engine is made simple by the fact that no pump is needed. The engine is made simple and light and can be used for instance as a to provide enough power to drive a television and lights. Bottled natural gas is widely available. The burning of natural gas solves lots of emission problems, because natural gas burns very efficiently in air without leaving difficult problems of emissions. Indeed it is envisaged that the engine of the present invention will run without any need for treatment of the exhaust gases, for instance without the need of a catalytic converter.

25

Preferably the inlet valve means comprises a one-way valve, the transfer valve means comprises a port cyclically opened and closed during motion of the reciprocating member and the exhaust valve means comprises a port cyclically opened and closed during motion of the reciprocating member. More preferably, the transfer valve means comprises a first transfer

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valve which can be opened in the first variable volume chamber and a second transfer port which can be opened in the second variable volume chamber and conduit means extending through the reciprocating member to  
5 connect the first and second transfer ports.

The first transfer port is devised in an inwardly facing surface of an end section wall of an open ended cylinder of the reciprocating member and the second  
10 transfer port is provided in an inwardly facing surface of an end section wall of the other open ended cylinder of the reciprocating member.

The present invention provides a simple  
15 construction wherein the flow of gases passes actually through the reciprocating member itself rather than through the housing surrounding the reciprocating member. This is a novel approach to the passage of gases.

20 As mentioned above, it is preferable that a first piston portion of the housing extends in a first of the open-ended cylinders and opens and closes the first transfer port present in the first open ended cylinder during reciprocation of the reciprocating  
25 member. It is also preferable that a second piston portion of the housing extends in a second of the open-ended cylinders and acts as a piston in the second open ended cylinder and opens and closes the second transfer port present in the second open ended  
30 cylinder during reciprocation of the reciprocating member. Ideally, the exhaust valve means comprises an exhaust port which can be opened in the second variable volume chamber and conduit means extending  
35 through the reciprocating member to connect the

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exhaust port to the fluid outlet. The exhaust port provided will be advantageously provided on the inwardly facing surface of the end section wall of the second open ended cylinder, the exhaust port being  
5 located opposite the second transfer port. It is preferred that the second piston portion of the housing controls the opening and closing of the exhaust port by opening and closing the exhaust port during reciprocation of the reciprocating member.

10

It will be appreciated that the engine is simple in construction, operates on a two-stroke cycle and uses scavenging to remove at least some of the combusted gas to exhaust. The scavenging will permit  
15 some exhaust gas recirculation, because some exhaust gases will inevitably remain along with the fresh incoming charge, for subsequent combustion. This may improve the emissions of the engine.

20

Preferably during each reciprocation of the reciprocating member, the second piston portion of the housing sequentially:

opens the exhaust port to allow combusted gases to flow from the second variable volume chamber;

25

opens the second transfer port to allow admittance of a charge of air into the second variable volume chamber to scavenge combusted gases out of the second variable volume chamber through the exhaust port and to supply air for combustion;

30

closes the second transfer port to prevent air being expelled through the transfer port during compression; and

closes the exhaust port to seal the second variable volume chamber ready for combustion.

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Preferably, the second piston portion of the housing which acts as a piston in the second variable volume chamber is provided with a cut-out portion located adjacent the second transfer port when the second transfer port is open which defines a region where combustion is commenced. Preferably, the fuel delivery means delivers fuel to the region of the second variable volume chamber defined by the cut out portion in the second piston portion of the housing.

10

Preferably the fuel and air mixture is ignited by active radical combustion. Active radical combustion is a new combustion mechanism recognised in the art in which the fuel/air mixture commences combustion spontaneously due to the presence of free radical ions in the mixture along with an elevated pressure and an elevated temperature of the mixture. The free radical ions are most advantageously introduced by the retention of exhaust gases in the mixture and the use of a two-stroke cycle with scavenging actively assists this. Indeed, the scavenging arrangement preferred in the present invention is a well-proven system which gives a well balanced distribution of fuel/air which is very good for auto ignition. The active radical combustion gives stable and clean combustion, particularly when an engine is run at a steady speed. It is envisaged that the very simple engine of the present invention will use active radical combustion with a two-stroke cycle and will operate as a steady state or a reasonably steady state with perhaps a full load condition and a half-load condition.

30

The machine of the present invention can be provided with a spark ignition means which operates in the region of the second variable volume chamber when

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ignition is commenced. The spark ignition means can be used either instead of active radical combustion or in combination with active radical combustion. It is preferred that active radical combustion is used  
5 alongside spark ignition, because the spark ignition will ensure combustion at a particular time, whilst the active radical combustion will ensure combustion which provides very low levels of NO<sub>x</sub> hydrocarbons and carbon monoxide.

10

Preferably the housing has conduit means passing therethrough which allow cooling air to be drawn from, and expelled to, the atmosphere for passing over and cooling of the reciprocating member. The  
15 reciprocating member can itself have cooling passages passing therethrough which allow passage of cooling air through the reciprocating member. Again, the use of air cooling provides a very simple engine, which does not, for instance, require a water pump.

20

Preferably the engine comprises an electrical winding in the housing surrounding the reciprocating member and the reciprocation of the reciprocating member is used to generate electrical power with the  
25 electrical winding being connectable to an electrical load. For instance, the present invention could be used as an engine in a hybrid vehicle. The reciprocating member can generate single phase alternating current. Three-phase alternating current  
30 would then be provided by use of an inverter. The present invention integrates the generator into the engine itself by providing an electrical coil in the cylinder liner. The electrical coil is therefore brought very close to the reciprocating member and  
35 this aids considerably the efficiency for generators.

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The coil is adjacent to the reciprocating member and there is no cylinder liner inbetween which will attenuate the flux linkage. The clearance between the coil and the reciprocating member can be reduced to  
5 perhaps 1/1000 th of an inch, ensuring maximum efficiency of the electrical circuit.

The present invention provides a good combination of engine and generator because essentially the engine  
10 is turned inside out, with the what would normally be the cylinder block in fact providing the pistons and what would normally be the piston providing the cylinders. This facilitates a good interaction between the reciprocating member and the coil  
15 surroundings.

It is envisaged that the present invention would fill the gap between current technology and fuel cell technology and could provide an immediate hybrid power  
20 solution for vehicles, where the delay to produce hybrid vehicles has been in part due to the complexity and cost of existing engines and fuel cell systems. The present engine would also be very useful as a static generator. The generator could be used as a  
25 generator for electrical power for electrical actuators in a vehicle which are now more common and which are more efficient and more in place of hydraulic actuators. The combined generator engine in a vehicle could be provided with a socket for outside  
30 uses so that the engine could not only provide power for powering electric motors driving a vehicle, but also external power, e.g. of 50 Hz, for powering electrical apparatus used outside the vehicle.

35 The present invention also provides a use of the

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machine described above in its operation as an engine in which one machine is used in tandem with a second machine, with the reciprocal members of the first and second machines lying on the same axis of reciprocation and with the reciprocal members of the first and second machines connected to move together and with the timing of both machines chosen so that whilst combusted gases are expanded in one machine a charge of fuel and air is being compressed in the other machine. The coupling of the two pistons together would utilise the combustion of fuel and air mixture in one engine with the subsequent expansion of gases as power for compressing charge air in the other engine.

In a further aspect, the machine of the present invention could also be used as a compressor with the reciprocating member driven to reciprocate by electrical power supplied to the electrical winding of the machine, wherein during reciprocation:

the charge of gas is drawn into the first variable volume chamber via the fluid inlet;

a charge of gas drawn into the first variable volume chamber is compressed in the first variable volume chamber;

the compressed gas is delivered via the transfer valve means to the second variable volume chamber;

the compressed gas delivered to the second variable volume chamber is compressed further in the second variable volume chamber;

the compressed gas in the second variable volume chamber is expelled via the outlet means to the outlet.

Preferably the inlet valve means in the

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compressor embodiment of the invention comprises a first one way valve which allows gas to pass from the fluid inlet into the first variable volume chamber and does not allow gas to pass from the first variable  
5 volume chamber out of the fluid inlet, the first one way valve allowing passage of gas from the fluid inlet to the first variable volume chamber only after a pressure differential of a first magnitude is established thereacross.

10

Preferably the transfer valve means comprises a second one way valve which allows gas to pass from the first variable volume chamber to the second variable volume chamber and which prevents gas flowing from the  
15 second variable volume chamber to the first variable volume chamber, the second one way valve allowing passage of gas from the first to the second variable volume chamber only when a pressure differential is established thereacross of a second magnitude.

20

Preferably the outlet valve means comprises a third one way valve which allows gas to be expelled from the second variable volume chamber to the fluid outlet and prevents gas being drawn into the second  
25 variable volume chamber via the fluid outlet, the third one way valve allowing expulsion of gas from the second variable volume chamber only when a pressure differential is established thereacross of a third magnitude.

30

It will be appreciated that the compressor provided by the invention is a two-stage compressor, with the gas being compressed to a first level of pressure in the first variable volume chamber and the  
35 second level of pressure in the second variable volume

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chamber. Preferably the first, second and third one way valves are spring-biassed valves.

5 The compressor of the present invention is simple and cheap in construction.

10 The first variable volume chamber preferably has a cross-section taken perpendicularly of the axis of reciprocation which has a first area and the second variable volume chamber has a cross-section taken radially of the axis of reciprocation which has a second area smaller than the first area. Thus, for a given force on the reciprocating member the pressure applied to gas in the first variable volume chamber is less than the pressure applied to the gas in the second variable volume chamber.

20 Preferably the housing has a first piston portion which extends into the first variable volume chamber and matches in radial cross-section the first variable volume chamber and the housing has a second piston portion which extends into the second variable volume chamber and matches in radial cross-section the second variable volume chamber.

25 The present invention achieves its simplicity of construction by reversing the usual arrangement of components. The cylinders are provided by the reciprocating member and the pistons are provided by the static housing.

35 Preferably the inlet valve means is provided in the first piston portion of the housing and the outlet valve means is provided in the second piston portion. Preferably the transfer valve means is located in the



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middle section of the reciprocating member.

It is preferred that the second variable volume chamber has a maximum volume smaller than the maximum  
5 volume of the first variable volume chamber.

Preferably the engine has control means to control the electrical wave form used to power the electrical winding and thereby control the output of  
10 the machine.

Further embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

15 Figure 1 is a schematic cross-section of an internal combustion engine according to the present invention;

Figure 2 is a schematic cross-section taken through the internal combustion engine of Figure 1;

20 Figure 3 is a schematic representation of a combined pair of the internal combustion engines illustrated in Figures 1 and 2; and

Figure 4 is a schematic cross-section taken through a compressor according to the present  
25 invention.

Turning now to Figure 1, a cyclically operating fluid displacement machine can be seen in the form of an internal combustion engine 10. The internal  
30 combustion engine 10 comprises a housing 11 in which there reciprocates a reciprocating member 12. The reciprocating member 12 is reciprocal linearly along an axis of reciprocation 13 in the housing 11. The reciprocating member 12 defines with the housing 11 a  
35 first variable volume chamber 14 and a second variable

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volume chamber 15.

5 An inlet valve 16 in the form of a one-way spring  
biassed valve allows air to be drawn from air inlet 17  
into the first variable volume chamber 14 and prevents  
flow of air from the first variable volume chamber 14  
out of the air inlet 17.

10 The reciprocating member 12 comprises a middle  
section 18 which extends perpendicularly of the axis  
of reciprocation 13. The reciprocating member 12 also  
comprises two end sections 19 and 20 on opposite sides  
of the middle section 18. Each of the end sections 19  
and 20 comprises a wall extending generally parallel  
15 to the axis of reciprocation 13. Each of the end  
sections 19 and 20 defines with the middle section 18  
an open-ended cylinder open at one end. The housing  
11 has a first piston portion 21 which extends into a  
first of the open-ended cylinders of the reciprocating  
20 member 12 and which acts as a piston in the open-ended  
cylinder formed by the end-section 19. The first  
piston portion 21 and the first open-ended cylinder  
formed by the end section 19 together define the first  
variable volume chamber 14.

25

The housing 11 has a second piston portion 22  
which extends into the open ended cylinder defined by  
the end-section 20 and which acts as a piston in the  
open-ended cylinder defined by the end section 20.  
30 The second piston portion 22 and the open ended  
cylinder formed by the end section 20 together define  
the second variable volume chamber 15. Transfer of  
gas from the first variable volume chamber 14 to the  
second variable volume chamber 15 is permitted by  
35 three conduits 23, 24 and 25 (see Figure 2). Each

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conduit 23, 24, 25 runs from a transfer port which can open onto the first variable volume chamber 14 to a transfer port which can open onto a second variable volume chamber 15. For instance, as can be seen in  
5 Figure 1, the conduit 23 runs from a transfer port 26 which can open onto the variable volume chamber 14 to a transfer port 27 which can open onto the variable volume chamber 15. The transfer ports 26 and 27 are closed when they are aligned with and are covered  
10 respectively by the piston portions 21 and 22 of the housing 11. The transfer ports 26 and 27 are open when they are not aligned with and are not covered respectively by the piston portions 21 and 22.

15 A conduit 30 extends through the reciprocating member 12 and connects an exhaust port 31 openable in the variable volume chamber 15 with an exhaust 32 of the engine 10. The exhaust port 31 is located diametrically opposite the transfer ports 27, 33 and  
20 34, as can be seen in Figure 2.

It can also be seen in Figure 2 that the reciprocating member 12 has a circular radial cross-section. The end sections 19 and 20 of the  
25 reciprocating member 12 comprise each an annular wall spaced from the central axis of the reciprocating member 12, which is coincident with the axis of reciprocation 13. Each of the end section annular walls 19 and 20 are slidable in annular slots provided  
30 in the housing 11. Two annular slots 35 and 36 are provided one at each end of the housing 11. An annular ring seal 37 acts between the end section 19 and the slots 35 and an annular ring seal 38 acts between the slot 36 and the end section 20.

35

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An electrical winding 39 is provided in the housing 11 wound around the reciprocating member 12. The electrical winding 39 is annular in nature and extends parallel to and adjacent to the cylindrical  
5 outermost surface of the reciprocating member 12. The annular electrical winding 39 extends parallel to the axis of reciprocation 13 and has a length equivalent to at least the sum of the axial length of the reciprocating member 12 and the distance travelled by  
10 the reciprocating member 12 during each reciprocation.

The engine 10 uses compressed natural gas as a fuel. The compressed natural gas is contained in a pressurised container 40 which is connected by a pipe  
15 41 to a gas injector 42. The gas injector 42 regulates the flow of compressed natural gas into the second variable volume chamber 15, but the engine 10 does not include any pumping means for the fuel, instead relying upon the pressure of the pressurised  
20 gas itself.

The second piston portion 22 of the housing 11 is provided with a cut out portion 43 which is located adjacent the transfer ports 27, 33 and 34 when the  
25 transfer ports 27, 33 and 34 are open, i.e. the reciprocating member 12 is in its position shown in Figure 1, i.e. displaced to the left, with the volume of the second variable volume chamber 15 at or close to maximum volume and the volume of the first variable  
30 volume chamber 14 at or close to its minimum volume. The cut out portion 43 defines a region in the second variable volume chamber 15 in which combustion is commenced. A spark plug 44 is provided to operate in the region 43.

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- 20 -

The housing 11 is provided with cooling air inlets such as 45 and 46. These cooling air inlets 45 and 46 as shown are valved inlets, permitting cooling air to be drawn into the housing 11, but not expelled from the housing 11. Instead, cooling air outlets 77 and 78 are provided at the other end of the housing 11. Cooling air ducts 47 and 48 extend linearly along the length of the reciprocating member 12. As the reciprocating member 12 reciprocates, cooling air is drawn in through the cooling air inlets 45 and 46, passed through the cooling air ducts 47 and 48 and expelled through the cooling air outlets 77 and 78. In fact, the cooling air exhausted through the outlet 78 is mixed with exhaust gases passing through the exhaust 32.

In operation of the engine shown in Figures 1 and 2 a charge of air is drawn into the first variable volume chamber 14 via the fluid inlet 17 and via the one way inlet valve 16. The air is drawn into the first variable volume chamber 14 as the first variable volume chamber 14 increases in volume, i.e. when the reciprocating member 12 moves to the right of its position in Figure 1. As the reciprocating member 12 moves to increase the volume of the first variable volume chamber 14, a pressure differential is established across the one-way inlet valve 16 which allows admission of air into the first variable volume chamber 14. Air continues to be drawn into the chamber 14 until the chamber 14 reaches its maximum volume. At this point the one way valve 16 closes and the reciprocating member 12 acts to reduce the volume of the chamber 14.

The transfer port 26 is open throughout all or

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the majority of travel of the reciprocating member 12  
As the reciprocating member 12 acts to reduce the  
volume of the chamber 14, the air in the chamber 14 is  
compressed and also displaced through the transfer  
5 port 26 into the conduits 23, 24 and 25. Initially as  
the reciprocating member 12 acts to reduce the volume  
of the chamber 14, the transfer ports 27, 33 and 34  
are not open to the chamber 15, because they are  
sealed by the piston portion 22 of the housing 11. As  
10 the chamber 14 reaches its minimum volume and the  
chamber 15 reaches its maximum volume, the transfer  
ports 23, 24 and 25 become uncovered and the  
compressed air flows into the chamber 15 and scavenges  
from the chamber 15 combusted gases out through the  
15 exhaust port 31 to the exhaust 32. The air admitted  
via the transfer ports 27, 33 and 34 also forms fresh  
charge air for the engine 10.

Once the chamber 15 has reached its maximum  
20 volume then the direction of motion of the  
reciprocating member 12 will change and the  
reciprocating member 12 will act to reduce the volume  
of the chamber 15 and increase the volume of the  
chamber 14. The transfer ports 27, 33 and 34 are then  
25 covered and closed by the peripheral surface of the  
piston portion 22. The exhaust port 31 is  
subsequently closed by the piston portion 22. The  
chamber 15 is then closed and the air in the chamber  
15 becomes compressed as the reciprocating member 12  
30 moves to reduce the volume of the chamber 15.

Either when the exhaust port 31 is closed, or  
shortly before the exhaust port 31 becomes closed,  
pressurised gas is admitted to the chamber 15. The  
35 injector 42 controls the admission of pressurised gas.

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The mixture of gas and air in the chamber 15 is compressed after the exhaust port 31 is closed by the reduction in volume of the chamber 15. At or about the point where the volume of the chamber 15 is at its minimum, the spark plug 44 sparks and ignites the gas and air mixture. The combusted gas and air mixture then expands and forces the reciprocating member 12 to move as the volume of the chamber 15 increases. Eventually, the exhaust port 31 is uncovered and the expanding combusted gases can escape to the exhaust 32. The combusted gases are scavenged by the next charge of air admitted to the transfer ports 27, 33 and 34 and the whole cycle begins again.

The fuel/air mixture present in the chamber 15 before combustion will contain some exhaust gas and this is preferred. It is preferred because the exhaust gas will contain radical ions and will enable combustion of the fuel/air mixture by active radical combustion. Active radical combustion is known in the art and will not be explained in detail in the specification. In the preferred embodiment, active radical combustion occurs in parallel with combustion using spark ignition.

In the figure 1 embodiment of the invention the engine 10 comprises a spring 49 which acts between the housing 11 and the reciprocating member 12 to bias a reciprocating member 12 into a position where the chamber 15 has minimum volume and the chamber 14 has maximum volume. In this arrangement, after the combusted gases in chamber 15 have expanded, the spring 49 uses stored energy to return the reciprocating member 12 to a position in which the chamber 14 has maximum volume and the chamber 15

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minimum volume.

The reciprocation of the reciprocating member 12 will generate electricity by means of the electrical winding 39. The electrical winding 39 is connected to an electronic controller 50 which generates an alternating current sinusoidal waveform on the line 51. The line 51 is connected to an electrical load. The line 51 is also connected to an electronic controller 52 which controls the ignition of the spark plug 44 and controls injection of pressurised gas by the injector 42. The controller 52 can determine the position of the reciprocating member 12 relative to the housing 11 from the signal on the line 51.

Rather than using a spring such as spring 49, it is envisaged that two engines 10 can be used in tandem as illustrated in Figure 3. It can be seen in Figure 3 that the second variable volume chamber 15 of one of the engines 10 has its maximum volume when the second variable volume chamber 15 of the other engine 10 has its minimum volume. The two reciprocating members 12 are connected by a connecting rod 53. The expansion of the combusted gases in one of the engines 10 will cause both of the reciprocating members 12 in both engines 10 to move. In the arrangement shown, there will always be expansion of combusted gases in one of the engines so that there will always be an expanding force acting to move the reciprocating members 12. The expansion of combusted gases in one of the engines 10 acts to move the reciprocating members 12 in one direction and the expansion of the combusted gas in the other engine 10 acts to move the reciprocating members 12 in the opposite direction.

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It can be seen in Figure 3 that the controller 50 is common to both engines 10 and the line 51 is connected to an inverter 54 which produces three-phase alternating current on the line 55.

5

It will be appreciated from the above that the engine of the present invention provides a combined engine and electrical generator, suitable for use in, for instance, a hybrid electrical vehicle. In such a case, the engine would be connected to a combination of batteries and electric motors and would power the electric motors and/or generate electricity for storing in the batteries. It is also possible that the output line could be connected to a load outside of the vehicle, to power other electrical devices.

15

The engine 10 of the present invention can be designed to work at a specific frequency, which will be the natural frequency of the engine. The engine is designed to work in a steady state condition or perhaps in two different steady state conditions. The interaction of the reciprocating member 12 and the surrounding electrical winding 39 can allow some control of reciprocation of the reciprocating member 12 by use of the electrical controller 50. The frequency of reciprocation of the reciprocating member 12 and/or the amplitude of reciprocal movement can be varied to vary the current output. The current will be proportional to a maximum velocity of the reciprocating member 12.

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25  
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It is envisaged that the induction coil 39 will comprise enamelled wire.

35

The engine 10 described above can be started

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using the coil 39 powered by an electrical source such as a battery. The controller 50 can be used to energise the coil 39 in order to start the reciprocation of the reciprocating member 12. Once  
5 the reciprocating member 12 has started reciprocation then the controller 52 will start injection of pressurised gas and ignition of the spark plug 44. Timed opposing forces will be applied on the reciprocating member 12 under the control of the  
10 controller 50 during starting. The two coils of the two engines 10 of the Figure 3 arrangement will be controlled in tandem during starting in the Figure 3 arrangement. In other words, the coil 39 is used as part of an electrical motor to start the motion of the  
15 reciprocating member as well as a generator in extracting power from the engine. Typically the reciprocating member will be reciprocated three or four times before combustion is initiated.

20 It is envisaged that the coil 39 can be used in place of or in parallel with a spring such as 49 to apply an electromagnetic force which acts to reduce the volume of the chamber 15 and compress the charge therein. Electrical power would be supplied to the  
25 coil 39 to enable this to happen. As long as on average the power needed by the coil 39 to effect compression of the fuel/air charge is less than the power extracted by the coil from motion of the reciprocating member caused by expansion of combusted  
30 gases, the engine will produce electrical power. The coil can in effect act as an electrical equivalent to a flywheel. Use of a coil as the sole means of effecting compression of a fuel/air charge (without help of a spring) can be beneficial in ensuring  
35 accurate control of position of reciprocating member

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12.

The engine 10 can be operated in such a way that during operation the reciprocating member 12 can be held stationary for a pause of a controllable duration, under the control of an electromagnetic force applied by coil 39. For instance, the reciprocating member 12 could be held in a position in which the exhaust port 31 has just been closed. The coil 39 could then, after a pause, apply an electromagnetic force to compress the fuel/air charge in the chamber 15 and operation could start again. The use of periodically occurring variable length pauses could be used to vary the power output of the engine in place of a change of rate of reciprocation of the reciprocating member 12 since it is preferred that the reciprocating member 12 when reciprocating does so at a constant optimum rate.

It will be appreciated that the engine above provides a very simple construction engine of light weight and low cost. The engine effectively has a single moving part, the reciprocating member 12. The engine does not need complicated valving arrangements or cam shafts to drive such valves.

The cyclically operated fluid displacement machine of the present invention can also provide a compressor and an example of this is shown in Figure 4. In Figure 4 a compressor 100 is shown to comprise a housing 101 in which reciprocates a reciprocating member 102. The reciprocating member 102 is reciprocal along an axis of reciprocation 103. The reciprocating member 102 defines with the housing 101 a first variable volume chamber 104 and a second

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variable volume chamber 105. The first variable  
volume chamber 104 has a cross-section taken radially  
of the axis of reciprocation 13 which has a first area  
and the second variable volume chamber 105 has a  
5 cross-section taken radially of the axis of  
reciprocation 103 which has a second area smaller than  
the first area. The second variable volume chamber  
105 has a maximum volume smaller than the maximum  
volume of the first variable volume chamber 104. A  
10 one-way inlet valve 106 allows flow of gas from a gas  
inlet 107 into the first variable volume chamber 104,  
but does not allow gas to pass from the variable  
volume chamber 104 out of the gas inlet 107. The one  
way inlet valve 106 is spring-biassed and only allows  
15 gas to flow from the gas inlet 107 into the first  
variable volume chamber 104 when a pressure  
differential of a first magnitude is established  
thereacross. The reciprocating member 102 comprises a  
middle section 108 which extends perpendicularly of  
20 the axis of reciprocation 103. The reciprocating  
member 102 has two end sections 109 and 110 on  
opposite sides of the middle section 108. The end  
sections 109, 110 comprise walls extending generally  
parallel to the axis of reciprocation 103. Each end  
25 section 109, 110 defines with the middle section 108  
an open ended cylinder, open at one end. The housing  
101 has a first piston portion 111 which extends into  
the open ended cylinder defined in part by the end  
section 109. The piston portion 111 acts as a piston  
30 in the open ended cylinder defined in part by the end  
section 109. The first piston portion 111 and the  
open ended cylinder defined in part by the end section  
109 together define the first variable volume chamber  
104.

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A second piston portion 112 extends into the open ended cylinder defined in part by the wall 110. The piston portion 112 acts as a piston in the open ended cylinder defined in part by the end section 110 and the open ended cylinder and the piston portion 112 together define a second variable volume chamber 105.

The reciprocating member 102 has a generally circular radial cross-section and the end sections 109 and 110 each comprise an annular wall spaced from the central axis of the reciprocating member 102 which is coincident with the axis of reciprocation 103. The end section walls 109 and 110 are slidable in two annular slots 113 and 114 provided at opposite ends of the housing 101. A transfer one-way valve 115 which is spring biased is provided in the middle section 108 of the reciprocating member 102. The valve 115 allows gas to pass from the chamber 104 to the chamber 105 but does not allow gas to pass from the chamber 105 back to the chamber 104. The valve 115 is spring-biased and only allows gas to pass from the chamber 104 to the chamber 105 when a pressure differential is established thereacross which is of a second magnitude.

A third one-way valve 116 which is also spring-biased is provided in the piston portion 112 and allows gas to be expelled from the chamber 105 to a gas outlet 117. The one-way valve 116 allows gas to be expelled from the chamber 105 to the outlet 117 but does not allow gas to be drawn into the chamber 105 from the outlet 117. The valve 116 is spring-biased to allow gas to be expelled from the chamber 105 to the outlet 117 only when a pressure differential is established thereacross of a third magnitude.

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An annular electrical winding 118 surrounds the reciprocating member 112 and extends parallel to and is adjacent to the outwardly facing cylindrical surface of the reciprocating member 102. The  
5 electrical winding 118 extends parallel to the axis of reciprocation 103 and has a length equivalent to at least the sum of the axial length of the reciprocating member 102 and the distance travelled by the reciprocating member 102 in each reciprocation.

10 The electrical winding 118 is connected to a controller 119 which is connected to the source of electrical power 120. The controller 119 supplies to the coil 118 an electrical waveform controlled in such  
15 a way that the reciprocating member 102 is forced first one way and then the opposite way, in a timed fashion. The reciprocating member 102 is preferably caused to reciprocate back and forth at a frequency set by the electrical waveform supplied by the  
20 controller 119.

Starting with the volume of the chamber 104 at its minimum, the reciprocating member will be forced by the electromagnetic force applied by the coil 118  
25 to increase the volume of the chamber 104. This increasing in volume will establish a pressure differential across the inlet valve 106 and when this pressure differential is greater than the first magnitude mentioned above, the inlet valve 106 will  
30 open to allow gas to be drawn in from the gas inlet 107 into the chamber 104. Once the chamber 104 reaches its maximum volume then the one way valve 106 will close and the reciprocating member 102 will be forced by the magnetic force to reduce in volume the  
35 chamber 104. The gas in the chamber 104 will

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therefore be compressed. When the pressure of the compressed gas in the chamber 104 exceeds a second magnitude (mentioned above) the one way valve 115 will open and will allow gas to flow from the chamber 104 into the chamber 105 (which increases in size as the chamber 104 decreases in size). When the chamber 105 reaches its maximum volume and the chamber 104 reaches its minimum volume, then the one way valve 115 will close and the reciprocating member 102 will be forced again to increase the volume of the chamber 104 (drawing in gas as previously described) whilst at the same time reducing in volume the chamber 105. Since the chamber 105 is of a reduced cross-sectional area, the force on the reciprocating member 102 will result in a greater pressure being applied to the gas compressed in chamber 105. The gas compressed in chamber 105 is compressed until the pressure differential across the valve 116 reaches the third magnitude, at which point the valve 116 opens and allows the gas compressed in chamber 105 to escape via the gas outlet 117.

It will be appreciated that the compressor 100 provided by the invention is a two stage compressor of very simple construction. The output of the compressor can be controlled simply by controlling the electrical wave form used to power the electrical winding 118.

The construction of the compressor 100 is unusual in that the pistons are part of the static housing whilst the cylinders are part of a reciprocating member. This construction makes good use of the flux linkage between the annular electrical winding 118 and the reciprocating member 102, which is located

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adjacent to the electrical winding 118. The two stage compressor is effectively a single moving part machine.

5           Whilst above the open ended cylinders defined by the reciprocating member are circular in cross-section, it should be appreciated that the open ended cylinders could be of any cross-section and the use of the term "cylinder" should not require a circular  
10 cross-section but could include, for instance, a square cross-section, an oval cross-section, a rectangular cross-section or whatever shaped cross-section is most convenient.

15           Whilst in the engine 10 mentioned above the transfer ports, e.g. 26 are closed by the piston 21 when the chamber 14 is at minimum volume, the transfer ports opening onto the chamber 14 could be permanently open to the chamber 14 since control of transfer  
20 between chambers 14 and 15 is governed by the transfer ports 27, 33 and 34 which open onto the chamber 15.

          In the compressor 100 or the engine 10 mentioned above the reciprocating member 12, 102 could be of  
25 steel with good magnetic properties. Alternatively, a coil could be provided within the reciprocating member 12, 102 for instance to allow the use of a lighter member. A current could be run through (or induced in) such a coil to improve the performance of the  
30 machine.



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## CLAIMS

1. A cyclically operating fluid displacement machine which comprises:

5 a housing;

a reciprocating member reciprocable linearly along an axis of reciprocation in the housing and defining with the housing first and second variable volume chambers;

10 a fluid inlet connected to the first variable volume chamber;

a fluid outlet connected to the second variable volume chamber;

15 inlet valve means which allows flow of fluid through the fluid inlet into the first variable volume chamber and which prevents flow of fluid from the first variable volume chamber out of the fluid inlet;

20 transfer valve means which allows flow of fluid from the first variable volume chamber to the second variable volume chamber and which prevents flow of fluid from the second variable volume chamber to the first variable volume chamber;

25 outlet valve means which allows flow of fluid from the second variable volume chamber out of the fluid outlet and which prevents flow of fluid from the fluid outlet into the second variable volume chamber; wherein:

30 during movement of the reciprocating member in the housing in a first direction fluid is drawn into the first variable volume chamber and fluid in the second variable volume chamber is expelled from the second variable volume chamber via the fluid outlet; and

35 during movement of the reciprocating member in the housing in a second direction opposite to the

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first direction fluid is compressed in the first variable volume chamber and fluid is transferred from the first variable volume chamber via the transfer valve means to the second variable volume chamber;

5           characterised in that:

          the reciprocating member comprises a middle section which extends perpendicularly of the axis of reciprocation and two end sections on opposite sides of the middle section each of the end sections  
10       comprising a wall extending generally parallel to the axis of reciprocation and each of the end sections defining with the middle section an open-ended cylinder open at one end; and

          the housing has a first piston portion which  
15       extends into a first of the open-ended cylinders of the reciprocating member and which acts as a piston in the first open-ended cylinder with the first piston portion and the first open-ended cylinder together defining the first variable volume chamber; and

20       the housing has a second piston portion which extends into a second of the open-ended cylinders of the reciprocating member and which acts as a piston in the second open-ended cylinder with the second piston portion and the second open-ended cylinder together  
25       defining the second variable volume chamber.

2.    A machine as claimed in claim 1 wherein the reciprocating member has a generally circular radial cross-section and the end sections each comprise an  
30       annular wall spaced from a central axis of the reciprocating member.

3.    A machine as claimed in any one of the preceding claims comprising an electrical winding provided in  
35       the housing surrounding the reciprocating member, the

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electrical winding extending parallel to and adjacent to the end section walls of the reciprocating member.

4. A machine as claimed in claim 3 wherein the  
5 electrical winding extends parallel to the axis of the reciprocation of the reciprocating member and has a length equivalent at least to the sum of the axial length of the reciprocating member and the distance travelled by the reciprocating member in each  
10 reciprocation.

5. A machine as claimed in claim 4 in which the end section walls of the reciprocating member are slidable in slots defined in the housing and the electrical  
15 winding in the housing extends adjacent to and parallel with surfaces defining the slots.

6. A machine as claimed in claim 5 in which a seal is formed between the end sections of the  
20 reciprocating member and the slots in which they end section slides.

7. A machine as claimed in claim 6 wherein resilient means acts between the housing and the reciprocating  
25 member to bias the reciprocating member to move in one direction.

8. A machine as claimed in claim 7 wherein the resilient means acts to bias the reciprocating member  
30 to reduce the second variable volume chamber to a minimum volume.

9. A machine as claimed in any one of claims 1 to 8 wherein each of the inlet valve means, the outlet  
35 valve means and the transfer valve means comprises

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either a one-way valve which opens and closes under the action of a pressure differential thereacross or a ported valve comprising a port opening onto one of the variable volume chambers which is cyclically opened and closed by the reciprocating member during reciprocation.

10. A machine as claimed in claim 9 in which the inlet valve means comprises a spring-biassed one way valve.

11. A machine as claimed in any one of claims 1 to 10 which functions as an internal combustion engine wherein:

a charge of air is drawn into the first variable volume chamber via the fluid inlet;

the charge of air drawn into the first variable volume chamber is compressed;

the compressed charge of air is delivered via the transfer valve means to the second variable volume chamber;

the machine comprises fuel delivery means which delivers fuel to the second variable volume chamber for mixing with the compressed charge of air;

the compressed charge mixture of fuel and air is combusted and allowed to expand in the second variable volume chamber; and

the expanded combusted mixture is scavenged from the second variable volume chamber by a subsequent charge of air delivered to the second variable volume chamber via the transfer valve means.

12. A machine as claimed in claim 11 wherein the fuel used is compressed natural gas and the machine comprises storage means for storing the natural gas in

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a pressurised state and wherein the fuel delivery means controls flow of the pressurised natural gas into the second variable volume chamber without use of pumping means.

5

13. A machine as claimed in claim 11 or claim 12 wherein the inlet valve means comprises a one-way valve, the transfer valve means comprises a port cyclically opened and closed during motion of the reciprocating member and the exhaust valve means comprises a port cyclically opened and closed during motion of the reciprocating member.

14. A machine as claimed in claim 13 wherein the transfer valve means comprise a first transfer port which can be opened in the first variable volume chamber and a second transfer port which can be opened in the second variable volume chamber and conduit means extending through the reciprocating member to connect the first and second transfer ports.

15. A machine as claimed in claim 14 wherein the first transfer port is provided in an inwardly facing surface of an end section wall of one open-ended cylinder of the reciprocating member and the second transfer port is provided in an inwardly facing surface of an end section wall of the other open-ended cylinder of the reciprocating member.

16. A machine as claimed in claim 15 wherein a first piston portion of the housing extends in a first of the first open-ended cylinders and acts as a piston in the first open-ended cylinder and opens and closes the first transfer port present in the first open-ended cylinder during reciprocation of the reciprocating

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member and wherein a second piston portion of the housing extends in a second of the open-ended cylinders and acts as a piston in the second open-ended cylinder and opens and closes the second transfer port present in the second open-ended cylinder during reciprocation of the reciprocating member.

17. A machine as claimed in any one of claims 13 to 16 wherein the exhaust valve means comprise an exhaust port which can be opened in the second variable volume chamber and conduit means extending through the reciprocating member to connect the exhaust port to the fluid outlet.

18. A machine as claimed in claim 17 wherein the exhaust valve means comprises an exhaust port provided on the inwardly facing surface of the end section wall of the second open-ended cylinder, the exhaust port being located opposite the second transfer port.

19. A machine as claimed in claim 18 wherein the second piston portion of the housing opens and closes the exhaust port during reciprocation of the reciprocating member.

20. A machine as claimed in claim 19 wherein during each reciprocation of the reciprocating member the second piston portion of the housing sequentially:  
opens the exhaust port to allow combusted gases to flow from the second variable volume chamber;  
opens the second transfer port to allow admittance of a charge of air into the second variable volume chamber to scavenge combusted gases out of the second variable volume chamber through the exhaust

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port and to supply air for combustion;

closes the second transfer port to prevent air being expelled through the transfer port during compression; and

5 closes the exhaust port to seal the second variable volume chamber ready for combustion.

21. A machine as claimed in claim 19 or claim 20 wherein the second piston portion of the housing which  
10 acts as a piston in the second variable volume chamber is provided with a cut-out portion located adjacent the second transfer port when the second transfer port is open which defines a region wherein combustion is commenced.

15 22. A machine as claimed in claim 21 wherein the fuel delivery means delivers fuel to the region of the second variable volume chamber defined by the cut-out portion in the second piston portion of the housing.

20 23. A machine as claimed in claim 22 wherein the fuel and air mixture is ignited by ignition occasioned by the presence of radical ions along with electrical pressure and temperature conditions.

25 24. A machine as claimed in claim 22 or 23 wherein a spark ignition means is provided to operate in the region of the second variable volume chamber wherein combustion is commenced to ignite the compressed fuel  
30 and air mixture.

25. A machine as claimed in any one of claims 11 to 24 wherein the housing has conduit means passing  
35 therethrough which allow cooling air to be drawn from and expelled to the atmosphere for passing over and

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cooling of the reciprocating member.

26. A machine as claimed in claim 25 wherein the reciprocating member has cooling passages passing therethrough which allow passage of cooling air through the reciprocating member.

27. A machine as claimed in any one of claims 11 to 26 comprising an electrical winding in the housing surrounding the reciprocating member wherein the reciprocation of the reciprocating member is used to generate electrical power with the electrical winding being connectable to an electrical load.

28. Use of a first machine as claimed in any one of claims 11 to 27 in tandem with a second machine as claimed in any one of claims 11 to 27, with the reciprocable members of the first and second machines lying on the same axis of reciprocation and with the reciprocable members of the first and second machines connected to move together and with the timing of both machines chosen so that whilst combusted gases are expanding in one machine a charge of fuel and air is being compressed in the other machine.

29. A machine as claimed in any one of claims 4 to 8, which functions as a compressor with the reciprocating member driven to reciprocate by electrical power supplied to the electrical winding, wherein during reciprocation:

a charge of gas is drawn into the first variable volume chamber via the fluid inlet;

the charge of gas drawn into the first variable volume chamber is compressed in the first variable volume chamber;



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the compressed gas is delivered via the transfer valve means to the second variable volume chamber;

the compressed gas delivered to the second variable volume chamber is compressed further in the second variable volume chamber;

the compressed gas in the second variable volume chamber is expelled via the outlet valve means to the outlet.

30. A machine as claimed in claim 29 wherein the inlet valve means comprises a first one-way valve which allows gas to pass from the fluid inlet into the first variable valve chamber and does not allow gas to pass from the first variable volume chamber out of the fluid inlet, the first one way valve allowing passage of gas from the fluid inlet to the first variable volume chamber only after a pressure differential of a first magnitude is established thereacross.

31. A machine as claimed in claim 30 wherein the transfer valve means comprises a second one way valve which allows gas to pass from the first variable volume chamber to the second variable volume chamber and which prevents gas flowing from the second variable volume chamber to the first variable volume chamber, the second one way valve allowing passage of gas from the first to the second variable volume chamber only when a pressure differential is established thereacross of a second magnitude.

32. A machine as claimed in claim 31 wherein the outlet valve means comprise a third one way valve which allows gas to be expelled from the second variable volume chamber to the fluid outlet and which prevents gas being drawn into the second variable

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volume chamber via the fluid outlet, the third one way  
valve allowing expulsion of gas from the second  
variable volume chamber only when a pressure  
differential is established thereacross of a third  
5 magnitude.

33. A machine as claimed in claim 32 wherein each of  
the first, second and third one-way valves are spring  
biassed valves.

10

34. A machine as claimed in any one of claim 21 to 33  
wherein the first variable volume chamber has a cross-  
section taken radially of the axis of reciprocation  
which has a first area and the second variable volume  
15 chamber has a cross-section taken radially of the axis  
of reciprocation which has a second area smaller than  
the first area.

35. A machine as claimed in claim 34 wherein the  
20 housing has a first piston portion which extends into  
the first variable volume chamber and matches in  
radial cross-section the first variable volume chamber  
and the housing has a second piston portion which  
extends into the second variable volume chamber and  
25 matches in radial cross-section the second variable  
volume chamber.

36. A machine as claimed in claim 35 wherein the  
inlet valve means is provided in the first piston  
30 portion and the outlet valve means is provided in the  
second piston portion.

37. A machine as claimed in claim 36 wherein the  
transfer valve means is located in the middle section  
35 of the reciprocating member.

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38. A machine as claimed in any one of claims 34 to 37 wherein the second variable volume chamber has a maximum volume smaller than the maximum volume of the first variable volume chamber.

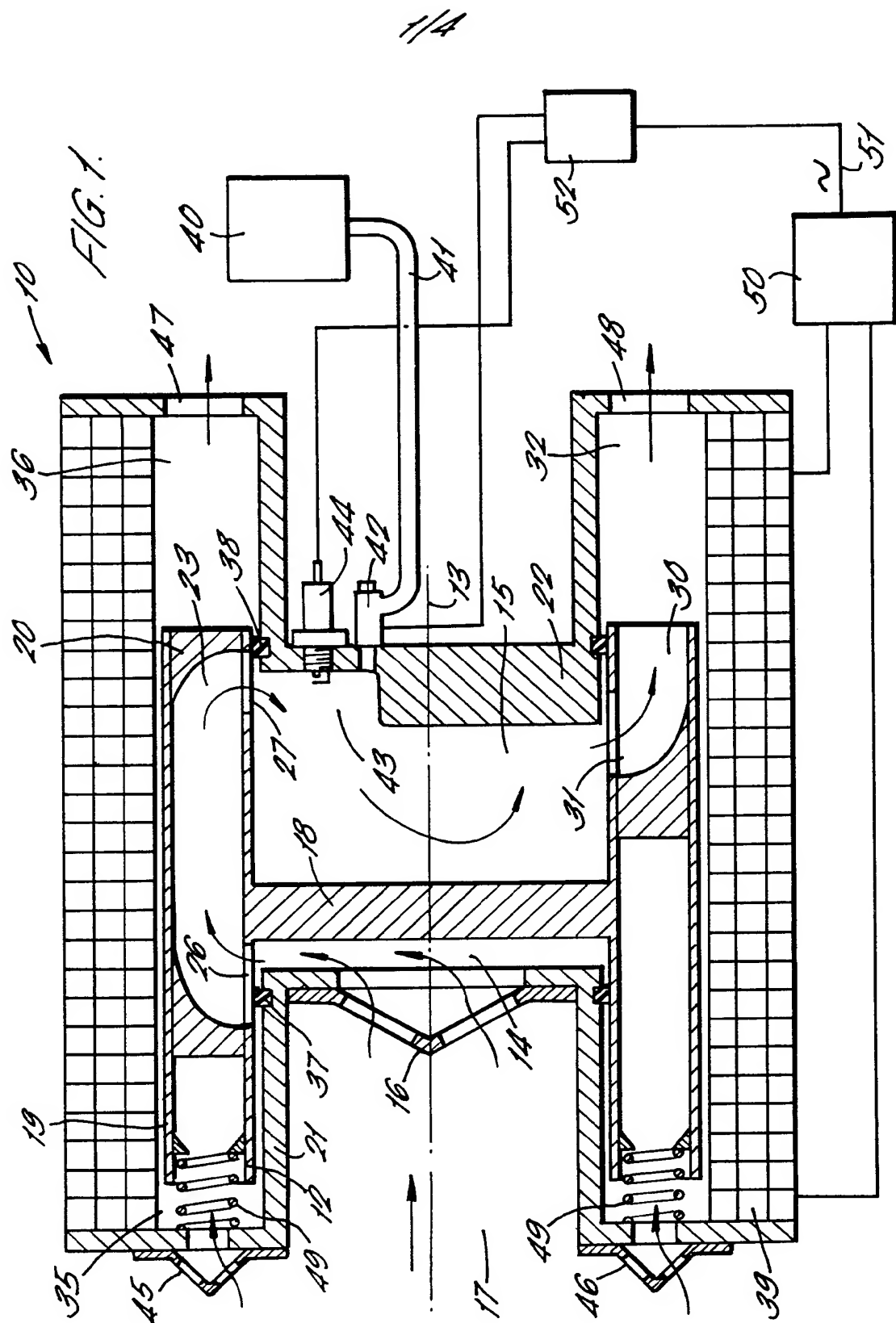
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39. A machine as claimed in any one of claims 29 to 37 wherein the control means is provided to control the electrical waveform used to power the electrical winding and thereby to control output of the machine.

10

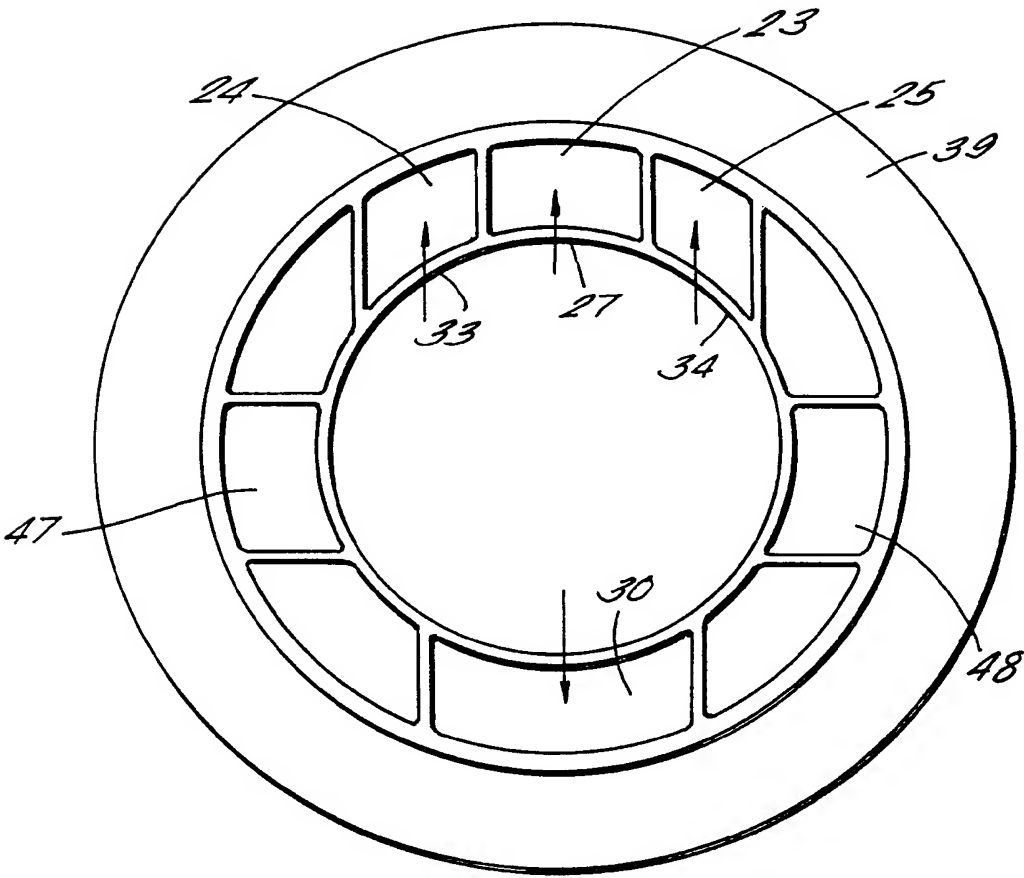
40. A machine substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

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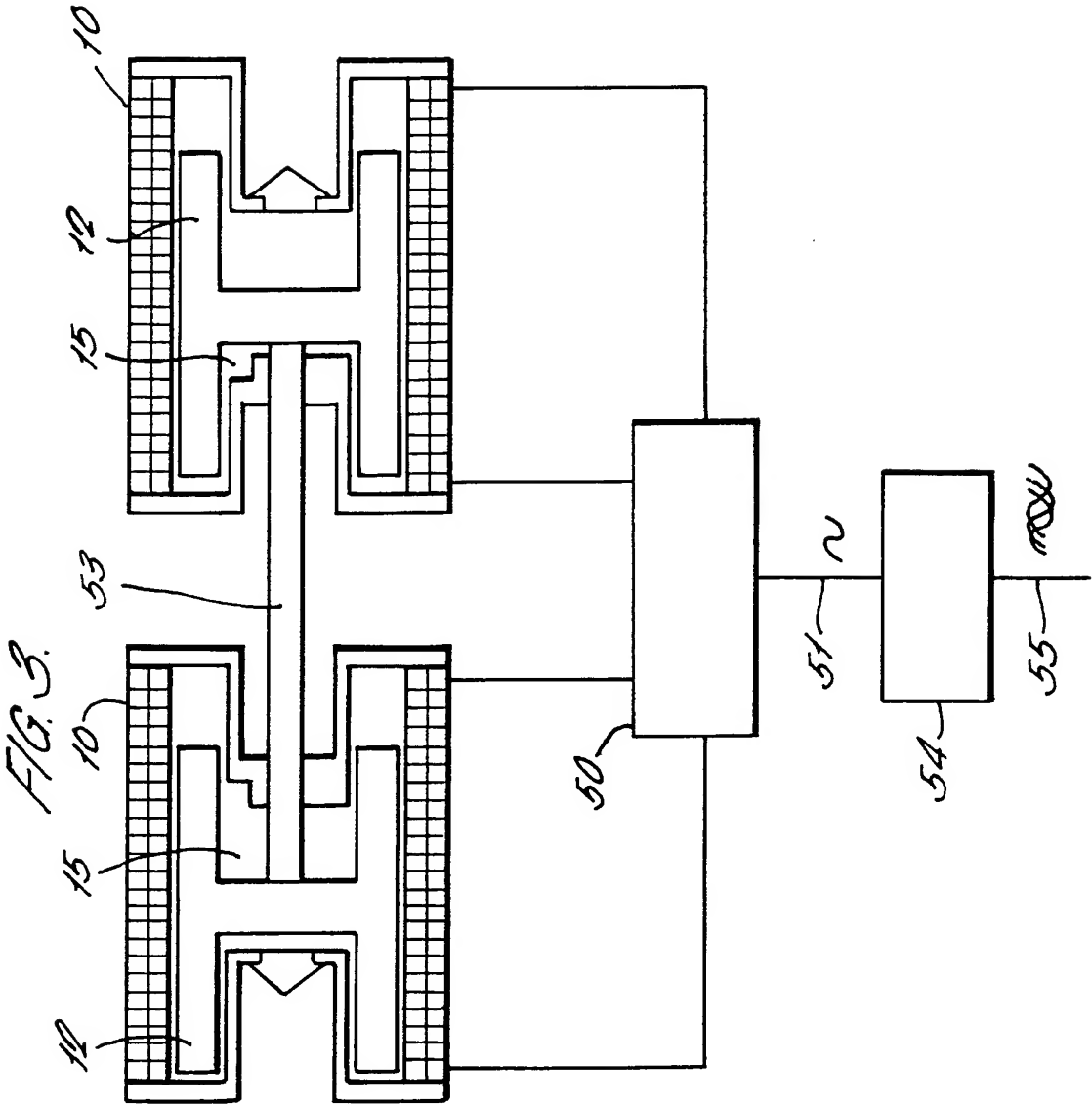


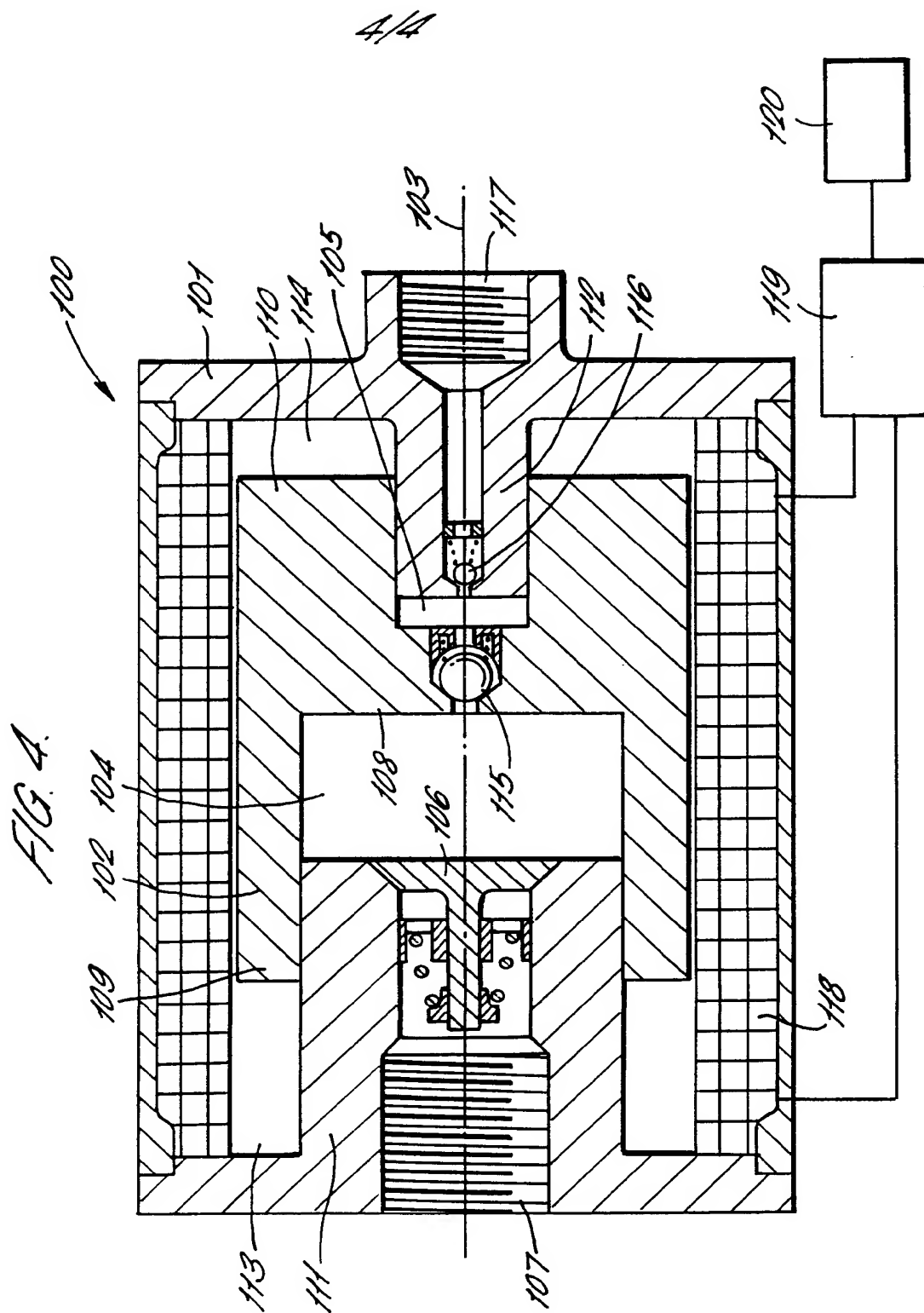
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FIG. 2.



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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 00/02260

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 F02B71/04 F02B75/30

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 F02B F01B F02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 172 784 A (VARELA JR ARTHUR A) 22 December 1992 (1992-12-22) cited in the application figures 3-5 abstract; claims 1-27 ---	1,3,28, 29,40
A	DE 28 32 909 A (HEESEN HANS NORBERT) 14 February 1980 (1980-02-14) figure 1 page 2, paragraph 3 ---	1,28,29, 40
A	FR 2 092 659 A (TASSINARI ROBERT) 28 January 1972 (1972-01-28) figures 1-3 page 2, line 1 - line 31 ---	1,2,28, 29,40
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

31 August 2000

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06/09/2000

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 00/02260

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